

The aid of TRNSYS simulation for the conservation of an artwork. A case study.

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ABSTRACT: Due to secularization more and more churches lose their original function, that is a place to worship, and become a place of cultural interest. To fulfil the comfort demands, a heating system or a HVAC-system was installed. These systems however impose new boundary conditions for the interior objects like paintings,... which may lead to damage. The case of the Saint-Bavo Cathedral in Ghent, Belgium is presented in this paper. In this church hangs the valuable polyptic 'The adoration of the mystic Lamb' painted by van Eyck. Use was made of a computer simulation to get insight in the working of different solutions to combine comfort and preservation. Because we want to be able in first instance to evaluate a whole year, a BES-software, was used. Using the dynamic simulation code TRNSYS the system performance in controlling thermal-hygrometric ambient parameters were obtained.

1 INTRODUCTION

Historic buildings are a part of our history. The last decades, more and more historical buildings receive a different function than the one they have originally been built for. Churches, castles, abbeys are converted into museums, cultural centres, living accommodations,... Looking specific to churches, due to secularization more and more churches lose their original function: a place to worship. The church building which often contains valuable interior objects like organs, paintings, pulpit become a place of cultural interest. To fulfil comfort demands of the visitors and employees, a heating system or a more sophisticated HVAC-system (Heating, Ventilation and Air-Conditioning) is introduced. The introduced systems however impose other temperature and relative humidity conditions which may cause damage on the artworks, and more specific on panel paintings.

There are different options to obtain insight in the indoor temperature and relative humidity: a measurement campaign and/or mathematical models. A measurement campaign gives insight into how the building temperature and humidity are related to the outdoor climate and heat sources. But a measurement campaign is quite time consuming and it only gives information of the actual setting of the building. The option of the use of a simulation study makes it possible to compare the effect on the indoor climate for different configurations. In the past, a

number of modelling techniques have been developed to predict heat and moisture transport. Two main categories of mathematical models are in wide use. The first are the microscopic scale models, which use computational fluid dynamics (CFD) to calculate the values of all relevant parameters at closely-spaced points in all parts of the flow field with a high degree of resolution. The second are the macroscopic scale models (often called multi-zone models) which calculate flows between zones; usually whole rooms in a building (Feilden, 1994). The chosen model depends on the scope of the problem.

The BES-software has a relatively short computation time in comparison with the CDF-models and is therefore more suitable for the simulation of longer time periods or for predicting the energy performance of a whole building. A large variety of multi-zone models for energy simulation exist. Common used macro scale models are TRNSYS, DOE-2, EnergyPlus, ESP-r. (Crawley, Hand, Kummert, & Griffith, 2008)

1.1 Case study

In this paper a simulation study of the baptistry in the Saint-Bavo Cathedral in Ghent, Belgium is described. In this church hangs the famous polyptic 'The adoration of the Mystic Lamb' painted by the brothers Van Eyck in 1453 (Figure 1). Many tourist coming from the whole world visit the church to watch the artistic masterpiece of the 15th -century Flemish painting.

In 2008 a thorough examination performed by the Flemish cultural heritage guard service has proven that the present climate was not sufficient to preserve the polyptic. So in 2010 a project was set up, with financial support from the Getty Foundation, for the preservation of the altarpiece. Ghent University was commissioned to evaluate the current environment and also to propose measures to improve the preservation of the altarpiece.

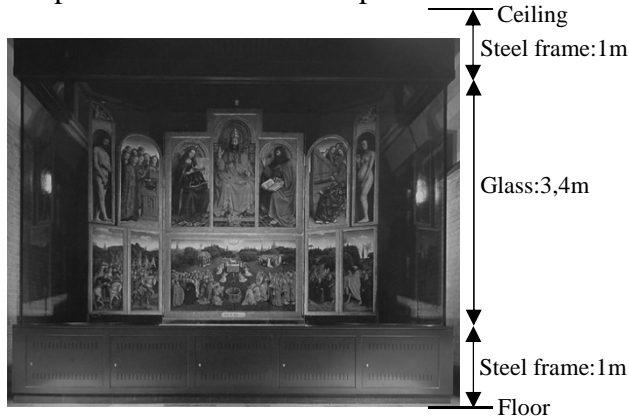


Figure 1. The polyptic ‘The adoration of the mystic Lamb’ located in the Saint Bavo’s baptistery in a glazed chamber.

One part was a measurement campaign which was started in February 2010. From these measurements was known that mainly the relative humidity fluctuations were too large. In 2011 some interventions were performed, partly to increase the comfort for the workers and partly to improve the preservation properties. The aim of this study was, to get insight in the working of the original climate and the new obtained climate with the aid of simulations. If the actual configuration is not satisfactory a new solution will be proposed.

1.2 Previous investigations

To preserve a panel painting ASHRAE (Anon, 2011) gave general guidelines for the temperature and relative humidity and in particular, the allowed fluctuations around an average value. The plants placed to answer the comfort demand, creates a different climate than the ‘historic’ climate and sometimes other fluctuations (because, for example, there is only heated during a church service or during the opening. Past investigations of the indoor climate pointed out drastic effects on the artworks; fast deteriorating or damage owing to the climate changes. (Bratasz, Kozlowski, Camuffo, & Pagan, 2007; Troi & Hausladen, 14 – 17 October 2006; van Schijndel, Schellen, & de Wit, 2009). Therefore there was tried to find a solution to meet the demands of comfort and preservation. For example, Troi (Troi & Hausladen, 14 – 17 October 2006) compared the climate caused by the four most important heating systems in 26 churches in South Tyrol, Italy. By this way, she demonstrates what the strengthens were of

the single heating systems and what kind of modifications could improve the situation in a particular church. Also Schellen (Schellen, 2002) discussed the different heating systems in a church: their advantages and disadvantages.

2 METHOD

A multi-zone model was carried out with the commercially building software TRNSYS v17 (Solar Energy Laboratory, 2010). The main strength of TRNSYS is its large libraries for HVAC and the building model that passed significant validation tests (Wetter & Haugstetter, 2006). With the aid of this software, the indoor conditions of the glazed chamber and baptistery could be predicted. First a model was made of the baptistery with his boundary conditions. For the calculations a time-step of one hour was used.

2.1 Geometrical model of the baptistery

The Saint-Bavo Cathedral is situated in the city Ghent in Belgium. The painting originally hung in the Vijdt chapel, but in 1986 the baptistery was selected as safe and new space for the exhibition of the painting. The baptistery is situated in the northwest tower of the church, and in this space the painting was enclosed in a bulletproof glazed chamber under a suspended concrete ceiling covered with a bitumen layer (Figure 2). As a results the baptistery became separated from the remaining part and there were no windows so that no sunlight felled into this space.

The walls of the baptistery were raised with a local calcareous sandstone and they measured between 1 and 2 m thick. The vertical walls of the glazed chamber consisted of 3,4 m-high windows embedded in a steel framework. Because the structure of the church floor was unknown the assembly was based on literature (Fawcett, 2001): a plain square paving stone, laid on a bed of lime mortar. In the glazed chamber the floor level was raised 12 cm by the construction of a new floor on the old one. The main geometric and thermal characteristics of the model are shown in Table 1.

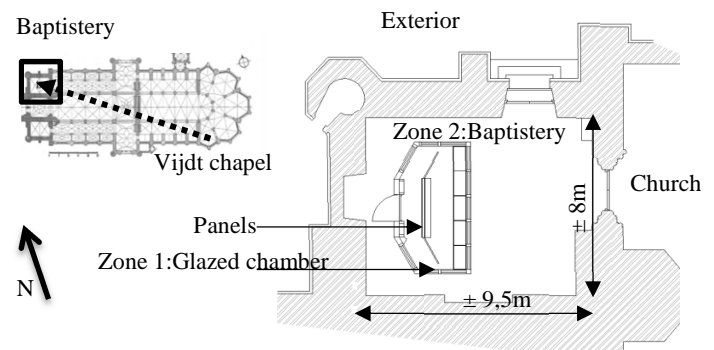


Figure 2. Floor plan of the baptistery and the shrine, located on the first floor of the West tower.

Table 1. Geometric and thermal characteristics of the model

Geometric values		Baptistery	Glazed chamber
Floor surface	m ²	65	15
Volume	m ³	260	105
R-value		Baptistery	Glazed chamber
Exterior wall	W/m ² K	0.47	-
Internal wall	W/m ² K	0.86	0.13
+ window			2.89
Ground floor	W/m ² K	0.26	0.22
Ceiling	W/m ² K	1.67	1.67

2.2 Boundary conditions of the model

In the simulation only the zones dedicated to the conservation of the painting were considered. By consequence the building model consisted of two zones as shown in Figure 2: the baptistery and the glazed chamber. The floor and walls of the baptistery were assumed to be boundaries with the church and the outdoor environment. For the climate of the church Hobo data loggers of the H8 Pro Series were placed near the baptistery. Outdoor climate conditions were handed by the Sterrenwacht of Ghent University.

Internal gains in the baptistery were the lights and the visitors. Lighting was minimal and was therefore assumed on 10W/m². The occupation rate of the baptistery was estimated on daily sold tickets. The visitors were allowed from 9h30 till 17h from Monday to Saturday and on Sunday from 13h till 17h in summer season. In the winter season the doors opened one hour later and closed one hour earlier: from 10h30 till 16h from Monday to Saturday and on Sunday from 13h till 16h. The thermal load for people was calculated based on an activity level 5 of the occupants (ASHRAE, 2001).

With the aid of the results from a tracer gas measurement the ventilation and infiltration of the baptistery and glazed chamber was modelled making use of TRNFLOW.

2.3 System configurations

The following kinds of configurations have been considered:

- No climate control is present. Only a visitor management was introduced; this means that the number of people in the baptistery is limited. There was calculated with the worst condition in which there were always 30 people present.
- A radiant panel heating on the ceiling of the baptistery (set point: 12°C) in combination with humidifier (set point 40% RH). This type of configuration was chosen to simulate as it is the system that operates at the moment.
- A single zone system. Temperature and relative humidity of the glazed chamber and baptistery were controlled by the baptistery. No cooling was provided. This type of configura-

tion was chosen to simulate as it was one of the options but because of financial reasons not practicable.

3 RESULTS AND DISCUSSION

The simulations results were compared with measured data in terms of indoor temperature and absolute humidity. In winter, simulation results were in good agreement with the measured data. In the summer there was an underestimation of the temperature. In addition there was also noticeable in the TRNSYS simulations that a certain lead time was needed, before the attenuated temperature was obtained. Further, deviations in the temperature and humidity course can be due to the estimations that were made for the simulation (see boundary conditions).

3.1 Visitor management

The visitor management had a very limited impact on the allowable temperature and relative humidity course. Yet this management is a simple measure to apply and to please the visitors by giving the necessary space to experience the painting.

3.2 Actual intervention: heating and humidifier

On Figure 3 hourly indoor temperature and relative humidity trends were shown for both the baptistery and glazed chamber when the heating works.

The simulations pointed out that heating by the radiant panels caused a temperature variation that was higher than before. As a result, the temperature in the baptistery fluctuated between 12 and 16°C when the heating was in device. This was in line with the measurements. One might wonder whether these larger temperature fluctuations raised the damage risk. Following the most strict requirements of ASHRAE(Anon, 2011) temperature fluctuations of ± 2 °C are permitted around a yearly average. Thereby, the fluctuations caused by the heating were smaller in the glazed chamber than in the baptistery. So, according to these standards the higher temperature fluctuations in the baptistery involved no risk for the painting. More dangerous was the influence of the heating on the relative humidity in the shrine. Although the heating ensures that the relative humidity was no longer too high (does not exceed the value of 80%), now the danger arose for a too low relative humidity. On the figure it can be seen that the daily relative humidity made large daily fluctuations, in which the absolute value of the relative humidity felled below 40%. To avoid this low value in RH, humidification was needed. Therefore in practice a mobile humidifier was placed in the glazed chamber. This however is not a solution to decrease

the large RH- fluctuations and thus to improve the conditions for the preservation for the painting; for this a more advanced control system is needed.

case and by consequence people complained in summer about headaches.

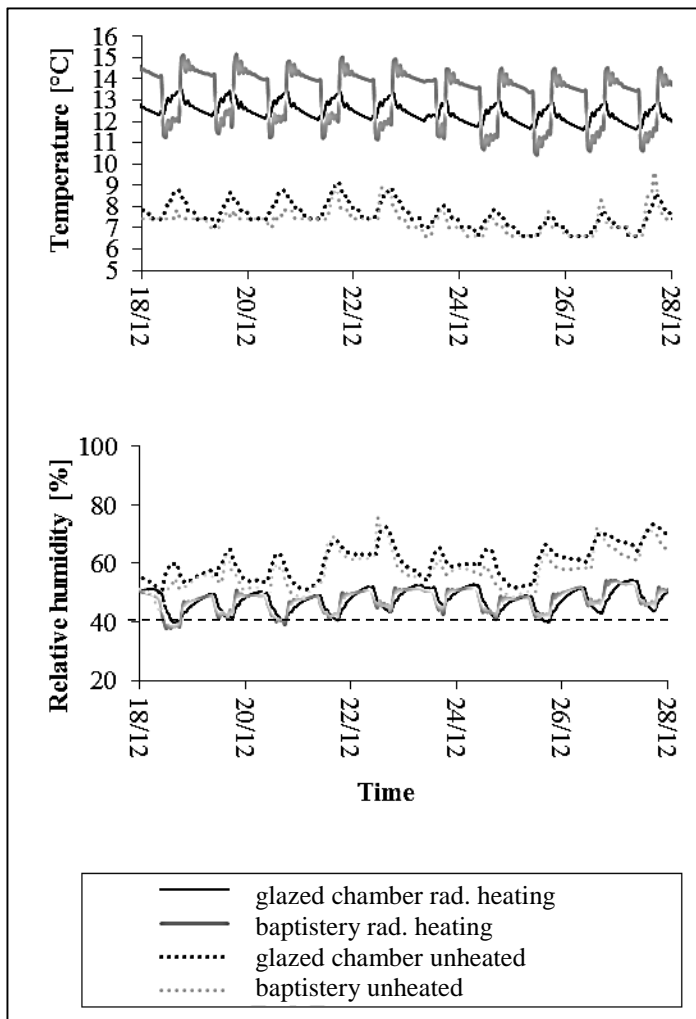


Figure 3: The effect on the temperature and relative humidity caused by radiant heating (values shown for one week when heating was needed) .

3.3 A simple HVAC-system

The system controls the temperature and relative humidity in the baptistery and this also indirect the glazed chamber in the baptistery. Measurements pointed out that annual average of the relative humidity in the baptistery and glazed chamber was 60%. To control the RH-fluctuations two options were studied: in the first the RH was allowed between 40 and 80%. The idea behind this was to avoid extreme values. Results pointed out that with these boundaries the RH fluctuated too much to obtain good conditions to preserve the painting. In the second options a smaller range for the RH was allowed: between 50-70%. Figure 4 shows that daily fluctuations were still present, but large differences were smoothed.

The advantage of a simple HVAC system is that besides the heating and humidification fresh air was supplied. Till now, in the baptistery this is not the

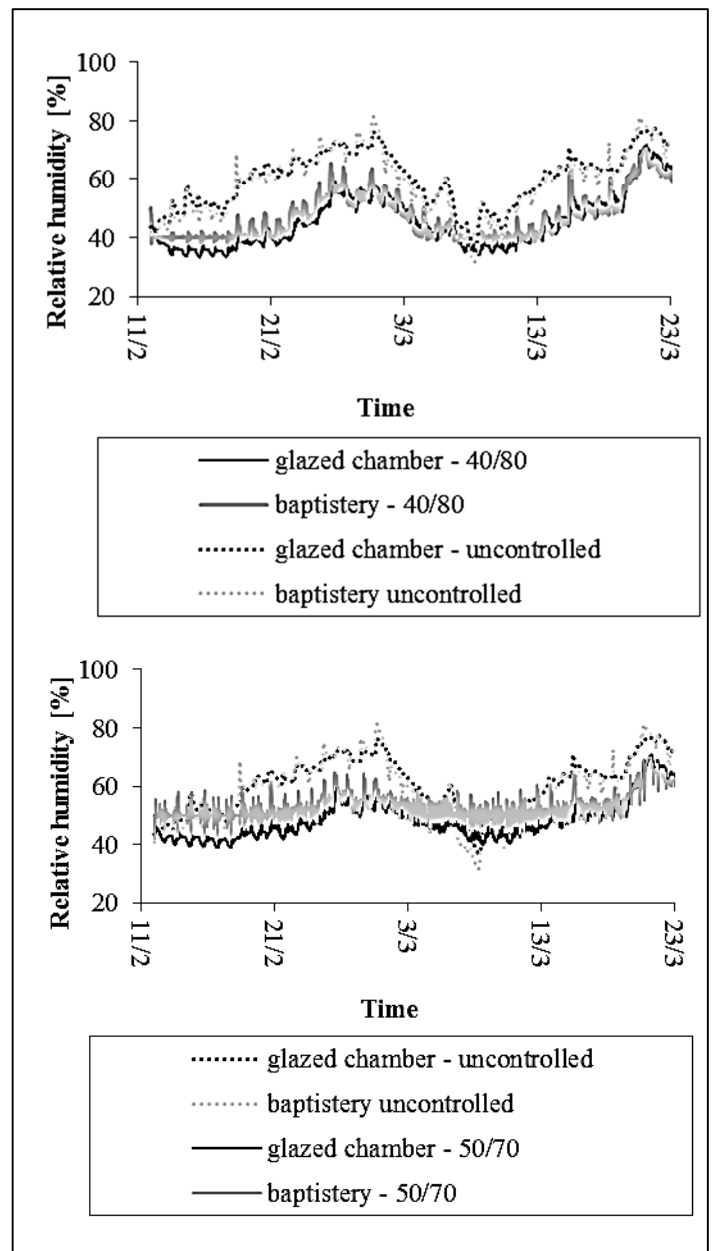


Figure 4: comparison of the relative humidity in the glazed chamber and the shrine for an allowable range of 40-80% and 50-70%.

4 CONCLUSION AND PERSPECTIVES

The simulations carried out in the paper a first attempt to create a model to look at the effect of specific interventions. Next to the originally and thus non-conditioned situation, three configurations were simulated: a visitor management, the actual heating system and a simple HVAC system.

The simulation results of the current heating system were confirmed by the measurements: temperature variations became higher and the RH-value in the shrine does no longer exceed the value of 80%. On the other hand a new problem arose: danger for

too low RH-values. This could be mended by humidification. Therefore in practice, a mobile dehumidifier was used in the glazed chamber. This provided the additional task for the supervisors to follow up the devices. Not doing this could cause a dangerous drop in RH. Besides this, the problem of the RH-fluctuations which are too large, has not improved and thus the conditions for the preservation for the painting. So further measures are needed.

Furthermore, a simulation was performed where the climate was controlled by a HVAC-system. To limit the RH-fluctuations a range of 50 till 70% RH was chosen for the simple HVAC system. The advantage of a simple HVAC system is that besides the heating and humidification fresh air is supplied. Therefore, it would be useful in further research to look at the cost price in addition to the thermohygric performance. Because a heating system was already placed there will be searched for a solution where the heating can be maintained in addition with fresh air supply and a device to control the moisture fluctuations. Also interesting is to study the option to allow seasonal variations in the relative humidity while limiting the short-term fluctuations. This seems at first sight a better system because with the simple HVAC system a tighter band was needed to avoid the large short-time fluctuations.

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